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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for nonprovisional applications under 37 CFR § 1.53(b))

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First Inventor or Application Identifier	Scott E. Moore
Title	METHODS AND APPARATUS FOR REMOVING CONDUCTIVE MATERIAL FROM A MICROELECTRONIC SUBSTRATE
Express Mail Label No.	EL404935092US

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Box Patent Application, Assistant Commissioner for Patents, Washington, D.C. 20231

1. [X] Authorization for Extensions & Fee Transmittal *(Submit an original and a duplicate for fee processing)*
2. [X] Specification [Total Pages] 37 *(preferred arrangement set forth below)*
   - Descriptive Title of the Invention
   - Cross References to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to Microfiche Appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
3. [X] Drawing(s) *(35 USC 113)* [Total Sheets] 8
4. Oath or Declaration [Total Pages] 1
   a. [X] Newly executed (original or copy)
   b. [ ] Copy from a prior application (37 CFR 1.63(d)) *(for continuation/divisional with Box 16 completed)*
      i. [ ] DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b)

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5. [ ] Microfiche Computer Program *(Appendix)*
6. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
   a. [ ] Computer-Readable Copy
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   c. [ ] Statement verifying identity of above copies

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ACCOMPANYING APPLICATION PARTS

7. [X] Assignment Papers (cover sheet & document(s))
8. [X] 37 CFR 3.73(b) Statement *(when there is an assignee)* [X] Power of Attorney
9. [ ] English Translation Document *(if applicable)*
10. [ ] Information Disclosure Statement (IDS)/PTO-1449 [ ] Copies of IDS Citations
11. [ ] Preliminary Amendment
12. [X] Return Receipt Postcard
12. [ ] Small Entity Statement(s) [ ] Statement filed in prior application, Status still proper and desired
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16. If a CONTINUING APPLICATION, *check appropriate box and supply the requisite information below and in a preliminary amendment*

[ ] Continuation [ ] Divisional [ ] Continuation-In-Part (CIP) of prior Application No.: ______________

Prior application information: Examiner ______________ *Group / Art Unit* ______________

For CONTINUATION or DIVISIONAL apps only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

[ ] Claims the benefit of Provisional Application No. ______________

17. CORRESPONDENCE ADDRESS

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PATENT TRADEMARK OFFICE

Respectfully submitted,

TYPED or PRINTED NAME JOHN M. WECHKIN REGISTRATION NO. 42,216

SIGNATURE [signature] Date August 30, 2000

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METHODS AND APPARATUS FOR REMOVING CONDUCTIVE MATERIAL FROM A MICROELECTRONIC SUBSTRATE

TECHNICAL FIELD

This invention relates to methods and apparatuses for removing conductive material from microelectronic substrates.

BACKGROUND OF THE INVENTION

Microelectronic substrates and substrate assemblies typically include a semiconductor material having features, such as memory cells, that are linked with conductive lines. The conductive lines can be formed by first forming trenches or other recesses in the semiconductor material, and then overlaying a conductive material (such as a metal) in the trenches. The conductive material is then selectively removed to leave conductive lines extending from one feature in the semiconductor material to another.

Electrolytic techniques have been used to both deposit and remove metallic layers from semiconductor substrates. For example, an alternating current can be applied to a conductive layer via an intermediate electrolyte to remove portions of the layer. In one arrangement, shown in Figure 1, a conventional apparatus 60 includes a first electrode 20a and a second electrode 20b coupled to a current source 21. The first electrode 20a is attached directly to a metallic layer 11 of a semiconductor substrate 10 and the second electrode 20b is at least partially immersed in a liquid electrolyte 31 disposed on the surface of the metallic layer 11 by moving the second electrode downwardly until it contacts the electrolyte 31. A barrier 22 protects the first electrode 20a from direct contact with the electrolyte 31. The current source 21 applies alternating current to the substrate 10 via the electrodes 20a and 20b and the electrolyte 31 to remove conductive material from the conductive layer 11. The alternating current signal can have a variety of wave forms, such as those disclosed by Frankenthal et al. in a publication entitled, "Electroetching of Platinum in the Titanium-Platinum-Gold Metallization on Silicon Integrated Circuits" (Bell Laboratories), incorporated herein in its entirety by reference.

One drawback with the arrangement shown in Figure 1 is that it may not be possible to remove material from the conductive layer 11 in the region where the first electrode 20a is attached because the barrier 22 prevents the electrolyte 31 from contacting the substrate 10 in this region. Alternatively, if the first electrode 20a contacts the electrolyte in this region, the electrolytic process can degrade the first electrode 20a. Still a further drawback is that the electrolytic process may not uniformly remove material from the substrate 10. For example, "islands" of residual conductive material having no direct electrical connection to the first electrode 20a may develop in the conductive layer 11. The residual conductive material can interfere with the formation and/or operation of the conductive lines, and it may be difficult or impossible to remove with the electrolytic process unless the first electrode 20a is repositioned to be coupled to such "islands."

One approach to addressing some of the foregoing drawbacks is to attach a plurality of first electrodes 20a around the periphery of the substrate 10 to increase the uniformity with which the conductive material is removed. However, islands of conductive material may still remain despite the additional first electrodes 20a. Another approach is to form the electrodes 20a and 20b from an inert material, such as carbon, and remove the barrier 22 to increase the area of the conductive layer 11 in contact with the electrolyte 31. However, such inert electrodes may not be as effective as more reactive electrodes at removing the conductive material, and the inert electrodes may still leave residual conductive material on the substrate 10.

Figure 2 shows still another approach to addressing some of the foregoing drawbacks in which two substrates 10 are partially immersed in a vessel 30 containing the electrolyte 31. The first electrode 20a is attached to one substrate 10 and the second electrode 20b is attached to the other substrate 10. An advantage of this approach is that the electrodes 20a and 20b do not contact the electrolyte. However, islands of conductive material may still remain after the electrolytic process is complete, and it may be difficult to remove conductive material from the points at which the electrodes 20a and 20b are attached to the substrates 10.

SUMMARY

The present invention is directed toward methods and apparatuses for removing conductive materials from microelectronic substrates. A method in accordance with one aspect of the invention includes positioning a first conductive electrode proximate to the microelectronic substrate and positioning a second conductive electrode proximate to the microelectronic substrate and spaced apart from the first conductive electrode. The method further includes removing the conductive material from the microelectronic substrate by applying a varying current to at least one of the first and second electrodes while the first and second electrodes are spaced apart from the conductive material of the microelectronic substrate.

In a further aspect of the invention, the method can include disposing a dielectric layer between the microelectronic substrate and the first electrode and/or varying an amplitude of the current at a first frequency while superimposing on the first frequency an amplitude and/or polarity variation having a second frequency less than the first frequency. The rate at which conductive material is removed from the microelectronic substrate can be controlled by controlling a distance between at least one of the electrodes and the microelectronic substrate. The microelectronic substrate and/or the electrodes can be moved relative to each other to position the electrode at a selected position relative to the microelectronic substrate. In yet another aspect of the invention, a first electrolyte adjacent to the electrodes can be separated from a second electrolyte adjacent to the microelectronic substrate while maintaining an electrical connection between the electrolytes.

The invention is also directed toward an apparatus for removing conductive material from a microelectronic substrate. The apparatus can include a support member having at least one engaging surface to support the microelectronic substrate, and first and second electrodes. The first and second electrodes are spaced apart from the support member and the microelectronic substrate when the microelectronic substrate is supported by the support member, and at least one of the first and second electrodes is coupleable to a source of varying current. The electrodes can have a planform shape that corresponds to a planform shape of a portion of the microelectronic substrates and they can be arranged in pairs with the pairs distributed to control the distance between the electrodes and the microelectronic substrate. The apparatus can further include a sensor positioned at least proximate to the

support member to detect the rate at which the conductive material is removed from the microelectronic substrate and/or the amount of conductive material remaining on the microelectronic substrate. In still a further aspect of this embodiment, a polishing pad can be positioned proximate to the support member and can include a polishing surface for removing material from the microelectronic substrate by chemical and/or chemical-mechanical planarization as the polishing pad and/or the microelectronic substrate move relative to each other.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a partially schematic, side elevational view of an apparatus for removing conductive material from a semiconductor substrate in accordance with the prior art.

Figure 2 is a partially schematic side, elevational view of another apparatus for removing conductive material from two semiconductor substrates in accordance with the prior art.

Figure 3 is a partially schematic, side elevational view of an apparatus having a support member and a pair of electrodes for removing conductive material from a microelectronic substrate in accordance with an embodiment of the invention.

Figure 4 is a partially schematic, side elevational view of an apparatus for removing conductive material and sensing characteristics of the microelectronic substrate from which the material is removed in accordance with another embodiment of the invention.

Figure 5 is a partially schematic, side elevational view of an apparatus that includes two electrolytes in accordance with still another embodiment of the invention.

Figure 6 is a partially schematic, plan view of a substrate adjacent to a plurality of electrodes in accordance with still further embodiments of the invention.

Figure 7 is a cross-sectional, side elevational view of an electrode and a substrate in accordance with yet another embodiment of the invention.

Figure 8A is a partially schematic, isometric view of a portion of a support for housing electrode pairs in accordance with still another embodiment of the invention.

Figures 8B-8C are isometric views of electrodes in accordance with still further embodiments of the invention.

Figure 9 is a partially schematic, side elevational view of an apparatus for both planarizing and electrolytically processing microelectronic substrates in accordance with yet another embodiment of the invention.

Figure 10 is a partially schematic, partially exploded isometric view of a planarizing pad and a plurality of electrodes in accordance with still another embodiment of the invention.

Figure 11 is a partially schematic, side elevational view of an apparatus for both planarizing and electrolytically processing microelectronic substrates in accordance with still another embodiment of the invention.

Figures 12A-B schematically illustrate a circuit and wave form for electrolytically processing a microelectronic substrate in accordance with yet another embodiment of the invention.

DETAILED DESCRIPTION

The present disclosure describes methods and apparatuses for removing conductive materials from a microelectronic substrate and/or substrate assembly used in the fabrication of microelectronic devices. Many specific details of certain embodiments of the invention are set forth in the following description and in Figures 3-12B to provide a thorough understanding of these embodiments. One skilled in the art, however, will understand that the present invention may have additional embodiments, or that the invention may be practiced without several of the details described below.

Figure 3 is a partially schematic, side elevational view of an apparatus 160 for removing conductive material from a microelectronic substrate or substrate assembly 110 in accordance with an embodiment of the invention. In one aspect of this embodiment, the apparatus 160 includes a vessel 130 containing an electrolyte 131, which can be in a liquid or a gel state. A support member 140 supports the microelectronic substrate 110 relative to the vessel 130 so that a conductive layer 111 of the substrate 110 contacts the electrolyte 131. The conductive layer 111 can include metals such as platinum, tungsten, tantalum, gold, copper, or other conductive materials. In another aspect of this embodiment, the support member 140 is coupled to a substrate drive unit 141 that moves the support member 140 and the substrate 110 relative to the vessel 130. For example, the substrate drive unit 141 can

translate the support member 140 (as indicated by arrow "*A*") and/or rotate the support member 140 (as indicated by arrow "*B*").

The apparatus 160 can further include a first electrode 120a and a second electrode 120b (referred to collectively as electrodes 120) supported relative to the microelectronic substrate 110 by a support member 124. In one aspect of this embodiment, the support arm 124 is coupled to an electrode drive unit 123 for moving the electrodes 120 relative to the microelectronic substrate 110. For example, the electrode drive unit 123 can move the electrodes toward and away from the conductive layer 111 of the microelectronic substrate 110, (as indicated by arrow "*C*"), and/or transversely (as indicated by arrow "*D*") in a plane generally parallel to the conductive layer 111. Alternatively, the electrode drive unit 123 can move the electrodes in other fashions, or the electrode drive unit 123 can be eliminated when the substrate drive unit 141 provides sufficient relative motion between the substrate 110 and the electrodes 120.

In either embodiment described above with reference to Figure 3, the electrodes 120 are coupled to a current source 121 with leads 128 for supplying electrical current to the electrolyte 131 and the conductive layer 111. In operation, the current source 121 supplies an alternating current (single phase or multiphase) to the electrodes 120. The current passes through the electrolyte 131 and reacts electrochemically with the conductive layer 111 to remove material (for example, atoms or groups of atoms) from the conductive layer 111. The electrodes 120 and/or the substrate 110 can be moved relative to each other to remove material from selected portions of the conductive layer 111, or from the entire conductive layer 111.

In one aspect of an embodiment of the apparatus 160 shown in Figure 3, a distance D_1 between the electrodes 120 and the conductive layer 111 is set to be smaller than a distance D_2 between the first electrode 120a and the second electrode 120b. Furthermore, the electrolyte 131 generally has a higher resistance than the conductive layer 111. Accordingly, the alternating current follows the path of least resistance from the first electrode 120a, through the electrolyte 131 to the conductive layer 111 and back through the electrolyte 131 to the second electrode 120b, rather than from the first electrode 120a directly through the electrolyte 131 to the second electrode 120b. Alternatively, a low dielectric material (not shown) can be positioned between the first electrode 120a and the

second electrode 120b to decouple direct electrical communication between the electrodes 120 that does not first pass through the conductive layer 111.

One feature of an embodiment of the apparatus 160 shown in Figure 3 is that the electrodes 120 do not contact the conductive layer 111 of the substrate 110. An advantage of this arrangement is that it can eliminate the residual conductive material resulting from a direct electrical connection between the electrodes 120 and the conductive layer 111, described above with reference to Figures 1 and 2. For example, the apparatus 160 can eliminate residual conductive material adjacent to the contact region between the electrodes and the conductive layer because the electrodes 120 do not contact the conductive layer 111.

Another feature of an embodiment of the apparatus 160 described above with reference to Figure 3 is that the substrate 110 and/or the electrodes 120 can move relative to the other to position the electrodes 120 at any point adjacent to the conductive layer 111. An advantage of this arrangement is that the electrodes 120 can be sequentially positioned adjacent to every portion of the conductive layer to remove material from the entire conductive layer 111. Alternatively, when it is desired to remove only selected portions of the conductive layer 111, the electrodes 120 can be moved to those selected portions, leaving the remaining portions of the conductive layer 111 intact.

Figure 4 is a partially schematic, side elevational view of an apparatus 260 that includes a support member 240 positioned to support the substrate 110 in accordance with another embodiment of the invention. In one aspect of this embodiment, the support member 240 supports the substrate 110 with the conductive layer 111 facing upwardly. A substrate drive unit 241 can move the support member 240 and the substrate 110, as described above with reference to Figure 3. First and second electrodes 220a and 220b are positioned above the conductive layer 111 and are coupled to a current source 221. A support member 224 supports the electrodes 220 relative to the substrate 110 and is coupled to an electrode drive unit 223 to move the electrodes 220 over the surface of the support conductive layer 111 in a manner generally similar to that described above with reference to Figure 3.

In one aspect of the embodiment shown in Figure 4, the apparatus 260 further includes an electrolyte vessel 230 having a supply conduit 237 with an aperture 238 positioned proximate to the electrodes 220. Accordingly, an electrolyte 231 can be deposited locally in an interface region 239 between the electrodes 220 and the conductive layer 111,

without necessarily covering the entire conductive layer 111. The electrolyte 231 and the conductive material removed from the conductive layer 111 flow over the substrate 110 and collect in an electrolyte receptacle 232. The mixture of electrolyte 231 and conductive material can flow to a reclaimer 233 that removes most of the conductive material from the electrolyte 231. A filter 234 positioned downstream of the reclaimer 233 provides additional filtration of the electrolyte 231 and a pump 235 returns the reconditioned electrolyte 231 to the electrolyte vessel 230 via a return line 236.

In another aspect of the embodiment shown in Figure 4, the apparatus 260 can include a sensor assembly 250 having a sensor 251 positioned proximate to the conductive layer 111, and a sensor control unit 252 coupled to the sensor 251 for processing signals generated by the sensor 251. The control unit 252 can also move the sensor 251 relative to the substrate 110. In a further aspect of this embodiment, the sensor assembly 250 can be coupled via a feedback path 253 to the electrode drive unit 223 and/or the substrate drive unit 241. Accordingly, the sensor 251 can determine which areas of the conductive layer 111 require additional material removal and can move the electrodes 220 and/or the substrate 110 relative to each other to position the electrodes 220 over those areas. Alternatively, (for example, when the removal process is highly repeatable), the electrodes 220 and/or the substrate 110 can move relative to each other according to a pre-determined motion schedule.

The sensor 251 and the sensor control unit 252 can have any of a number of suitable configurations. For example, in one embodiment, the sensor 251 can be an optical sensor that detects removal of the conductive layer 111 by detecting a change in the intensity, wavelength or phase shift of the light reflected from the substrate 110 when the conductive material is removed. Alternatively, the sensor 251 can emit and detect reflections of radiation having other wavelengths, for example, x-ray radiation. In still another embodiment, the sensor 251 can measure a change in resistance or capacitance of the conductive layer 111 between two selected points. In a further aspect of this embodiment, one or both of the electrodes 220 can perform the function of the sensor 251 (as well as the material removal function described above), eliminating the need for a separate sensor 251. In still further embodiments, the sensor 251 can detect a change in the voltage and/or current drawn from the current supply 221 as the conductive layer 111 is removed.

In any of the embodiments described above with reference to Figure 4, the sensor 251 can be positioned apart from the electrolyte 231 because the electrolyte 231 is

concentrated in the interface region 239 between the electrodes 220 and the conductive layer 111. Accordingly, the accuracy with which the sensor 251 determines the progress of the electrolytic process can be improved because the electrolyte 231 will be less likely to interfere with the operation of the sensor 251. For example, when the sensor 251 is an optical sensor, the electrolyte 231 will be less likely to distort the radiation reflected from the surface of the substrate 110 because the sensor 251 is positioned away from the interface region 239.

Another feature of an embodiment of the apparatus 260 described above with reference to Figure 4 is that the electrolyte 231 supplied to the interface region 239 is continually replenished, either with a reconditioned electrolyte or a fresh electrolyte. An advantage of this feature is that the electrochemical reaction between the electrodes 220 and the conductive layer 111 can be maintained at a high and consistent level.

Figure 5 is a partially schematic, side elevational view of an apparatus 360 that directs alternating current to the substrate 110 through a first electrolyte 331a and a second electrolyte 331b. In one aspect of this embodiment, the first electrolyte 331a is disposed in two first electrolyte vessels 330a, and the second electrolyte 331b is disposed in a second electrolyte vessel 330b. The first electrolyte vessels 330a are partially submerged in the second electrolyte 331b. The apparatus 360 can further include electrodes 320, shown as a first electrode 320a and a second electrode 320b, each coupled to a current supply 321 and each housed in one of the first electrolyte vessels 330a. Alternatively, one of the electrodes 320 can be coupled to ground. The electrodes 320 can include materials such as silver, platinum, copper and/or other materials, and the first electrolyte 331a can include sodium chloride, potassium chloride, copper sulfate and/or other electrolytes that are compatible with the material forming the electrodes 320.

In one aspect of this embodiment, the first electrolyte vessels 330a include a flow restrictor 322, such as a permeable isolation membrane formed from Teflon™, sintered materials such as sintered glass, quartz or sapphire, or other suitable porous materials that allow ions to pass back and forth between the first electrolyte vessels 330a and the second electrolyte vessel 330b, but do not allow the second electrolyte 330b to pass inwardly toward the electrodes 320 (for example, in a manner generally similar to a salt bridge). Alternatively, the first electrolyte 331a can be supplied to the electrode vessels 330a from a first electrolyte source 339 at a pressure and rate sufficient to direct the first electrolyte 331a

outwardly through the flow restrictor 322 without allowing the first electrolyte 331a or the second electrolyte 330b to return through the flow restrictor 322. In either embodiment, the second electrolyte 331b remains electrically coupled to the electrodes 320 by the flow of the first electrolyte 331a through the restrictor 322.

In one aspect of this embodiment, the apparatus 360 can also include a support member 340 that supports the substrate 110 with the conductive layer 111 facing toward the electrodes 320. For example, the support member 340 can be positioned in the second electrolyte vessel 330b. In a further aspect of this embodiment, the support member 340 and/or the electrodes 320 can be movable relative to each other by one or more drive units (not shown).

One feature of an embodiment of the apparatus 360 described above as reference to Figure 5 is that the first electrolyte 331a can be selected to be compatible with the electrodes 320. An advantage of this feature is that the first electrolyte 331a can be less likely than conventional electrolytes to degrade the electrodes 320. Conversely, the second electrolyte 331b can be selected without regard to the effect it has on the electrodes 320 because it is chemically isolated from the electrodes 320 by the flow restrictor 322. Accordingly, the second electrolyte 331b can include hydrochloric acid or another agent that reacts aggressively with the conductive layer 111 of the substrate 110.

Figure 6 is a top plan view of the microelectronic substrate 110 positioned beneath a plurality of electrodes having shapes and configurations in accordance with several embodiments of the invention. For purposes of illustration, several different types of electrodes are shown positioned proximate to the same microelectronic substrate 110; however, in practice, electrodes of the same type can be positioned relative to a single microelectronic substrate 110.

In one embodiment, electrodes 720a and 720b can be grouped to form an electrode pair 770a, with each electrode 720a and 720b coupled to an opposite terminal of a current supply 121 (Figure 3). The electrodes 770a and 770b can have an elongated or strip-type shape and can be arranged to extend parallel to each other over the diameter of the substrate 110. The spacing between adjacent electrodes of an electrode pair 370a can be selected to direct the electrical current into the substrate 110, as described above with reference to Figure 3.

In an alternate embodiment, electrodes 720c and 720d can be grouped to form an electrode pair 770b, and each electrode 720c and 720d can have a wedge or "pie" shape that tapers inwardly toward the center of the microelectronic substrate 110. In still another embodiment, narrow, strip-type electrodes 720e and 720f can be grouped to form electrode pairs 770c, with each electrode 720e and 720f extending radially outwardly from the center 113 of the microelectronic substrate 110 toward the periphery 112 of the microelectronic substrate 110.

In still another embodiment, a single electrode 720g can extend over approximately half the area of the microelectronic substrate 110 and can have a semicircular planform shape. The electrode 720g can be grouped with another electrode (not shown) having a shape corresponding to a mirror image of the electrode 720g, and both electrodes can be coupled to the current source 121 to provide alternating current to the microelectronic substrate in any of the manners described above with reference to Figures 3-5.

Figure 7 is a partially schematic, cross-sectional side elevational view of a portion of the substrate 110 positioned beneath the electrode 720c described above with reference to Figure 6. In one aspect of this embodiment, the electrode 720c has an upper surface 771 and a lower surface 772 opposite the upper surface 771 and facing the conductive layer 111 of the substrate 110. The lower surface 772 can taper downwardly from the center 113 of the substrate 110 toward the perimeter 112 of the substrate 110 in one aspect of this embodiment to give the electrode 720c a wedge-shaped profile. Alternatively, the electrode 720c can have a plate-type configuration with the lower surface 772 positioned as shown in Figure 7 and the upper surface 771 parallel to the lower surface 772. One feature of either embodiment is that the electrical coupling between the electrode 720c and the substrate 110 can be stronger toward the periphery 112 of the substrate 110 than toward the center 113 of the substrate 110. This feature can be advantageous when the periphery 112 of the substrate 110 moves relative to the electrode 720c at a faster rate than does the center 113 of the substrate 110, for example, when the substrate 110 rotates about its center 113. Accordingly, the electrode 720c can be shaped to account for relative motion between the electrode and the substrate 110.

In other embodiments, the electrode 720c can have other shapes. For example, the lower surface 772 can have a curved rather than a flat profile. Alternatively, any of the electrodes described above with reference to Figure 6 (or other electrodes having shapes

other than those shown in Figure 6) can have a sloped or curved lower surface. In still further embodiments, the electrodes can have other shapes that account for relative motion between the electrodes and the substrate 110.

Figure 8A is a partially schematic view of an electrode support 473 for supporting a plurality of electrodes in accordance with another embodiment of the invention. In one aspect of this embodiment, the electrode support 473 can include a plurality of electrode apertures 474, each of which houses either a first electrode 420a or a second electrode 420b. The first electrodes 420a are coupled through the apertures 474 to a first lead 428a and the second electrodes 420b are coupled to a second lead 428b. Both of the leads 428a and 428b are coupled to a current supply 421. Accordingly, each pair 470 of first and second electrodes 420a and 420b defines part of a circuit that is completed by the substrate 110 and the electrolyte(s) described above with reference to Figures 3-5.

In one aspect of this embodiment, the first lead 428a can be offset from the second lead 428b to reduce the likelihood for short circuits and/or capacitive coupling between the leads. In a further aspect of this embodiment, the electrode support 473 can have a configuration generally similar to any of those described above with reference to Figures 1-7. For example, any of the individual electrodes (*e.g.*, 320a, 320c, 320e, or 320g) described above with reference to Figure 6 can be replaced with an electrode support 473 having the same overall shape and including a plurality of apertures 474, each of which houses one of the first electrodes 420a or the second electrodes 420b.

In still a further aspect of this embodiment, the electrode pairs 470 shown in Figure 8A can be arranged in a manner that corresponds to the proximity between the electrodes 420a, 420b and the microelectronic substrate 110 (Figure 7), and/or the electrode pairs 470 can be arranged to correspond to the rate of relative motion between the electrodes 420a, 420b and the microelectronic substrate 110. For example, the electrode pairs 470 can be more heavily concentrated in the periphery 112 of the substrate 110 or other regions where the relative velocity between the electrode pairs 470 and the substrate 110 is relatively high (see Figure 7). Accordingly, the increased concentration of electrode pairs 470 can provide an increased electrolytic current to compensate for the high relative velocity. Furthermore, the first electrode 420a and the second electrode 420b of each electrode pair 470 can be relatively close together in regions (such as the periphery 112 of the substrate 110) where the electrodes are close to the conductive layer 111 (see Figure 7) because the

close proximity to the conductive layer 111 reduces the likelihood for direct electrical coupling between the first electrode 420a and the second electrode 420b. In still a further aspect of this embodiment, the amplitude, frequency and/or waveform shape supplied to different electrode pairs 470 can vary depending on factors such as the spacing between the electrode pair 470 and the microelectronic substrate 110, and the relative velocity between the electrode pair 470 and the microelectronic substrate 110.

Figures 8B-8C illustrate electrodes 820 (shown as first electrodes 820a and second electrodes 820b) arranged concentrically in accordance with still further embodiments of the invention. In one embodiment shown in Figure 8B, the first electrode 820a can be positioned concentrically around the second electrode 820b, and a dielectric material 829 can be disposed between the first electrode 820a and the second electrode 820b. The first electrode 820a can define a complete 360° arc around the second electrode 820b, as shown in Figure 8B, or alternatively, the first electrode 820a can define an arc of less than 360°.

In another embodiment, shown in Figure 8C, the first electrode 820A can be concentrically disposed between two second electrodes 820b, with the dielectric material 829 disposed between neighboring electrodes 820. In one aspect of this embodiment, current can be supplied to each of the second electrodes 820b with no phase shifting. Alternatively, the current supplied to one second electrode 820b can be phase-shifted relative to the current supplied to the other second electrode 820b. In a further aspect of the embodiment, the current supplied to each second electrode 820b can differ in characteristics other than phase, for example, amplitude.

One feature of the electrodes 820 described above with respect to Figures 8B-8C is that the first electrode 820a can shield the second electrode(s) 820b from interference from other current sources. For example, the first electrode 820a can be coupled to ground to shield the second electrodes 820b. An advantage of this arrangement is that the current applied to the substrate 110 (Figure 7) via the electrodes 820 can be more accurately controlled.

Figure 9 schematically illustrates an apparatus 560 for both planarizing and electrolytically processing the microelectronic substrate 110 in accordance with an embodiment of the invention. In one aspect of this embodiment, the apparatus 560 has a support table 580 with a top-panel 581 at a workstation where an operative portion "W" of a

planarizing pad 582 is positioned. The top-panel 581 is generally a rigid plate to provide a flat, solid surface to which a particular section of the planarizing pad 582 may be secured during planarization.

The apparatus 560 can also have a plurality of rollers to guide, position and hold the planarizing pad 582 over the top-panel 581. The rollers can include a supply roller 583, first and second idler rollers 584a and 584b, first and second guide rollers 585a and 585b, and a take-up roller 586. The supply roller 583 carries an unused or pre-operative portion of the planarizing pad 582, and the take-up roller 583 carries a used or post-operative portion of the planarizing pad 582. Additionally, the first idler roller 584a and the first guide roller 585a can stretch the planarizing pad 582 over the top-panel 581 to hold the planarizing pad 582 stationary during operation. A motor (not shown) drives at least one of the supply roller 583 and the take-up roller 586 to sequentially advance the planarizing pad 582 across the top-panel 581. Accordingly, clean pre-operative sections of the planarizing pad 582 may be quickly substituted for used sections to provide a consistent surface for planarizing and/or cleaning the substrate 110.

The apparatus 560 can also have a carrier assembly 590 that controls and protects the substrate 110 during planarization. The carrier assembly 590 can include a substrate holder 592 to pick up, hold and release the substrate 110 at appropriate stages of the planarizing process. The carrier assembly 590 can also have a support gantry 594 carrying a drive assembly 595 that can translate along the gantry 594. The drive assembly 595 can have an actuator 596, a drive shaft 597 coupled to the actuator 596, and an arm 598 projecting from the drive shaft 597. The arm 598 carries the substrate holder 592 via a terminal shaft 599 such that the drive assembly 595 orbits the substrate holder 592 about an axis E-E (as indicated by arrow "R_1"). The terminal shaft 599 may also rotate the substrate holder 592 about its central axis F-F (as indicated by arrow "R_2").

The planarizing pad 582 and a planarizing solution 587 define a planarizing medium that mechanically and/or chemically-mechanically removes material from the surface of the substrate 110. The planarizing pad 582 used in the apparatus 560 can be a fixed-abrasive planarizing pad in which abrasive particles are fixedly bonded to a suspension medium. Accordingly, the planarizing solution 587 can be a "clean solution" without abrasive particles because the abrasive particles are fixedly distributed across a planarizing surface 588 of the planarizing pad 582. In other applications, the planarizing pad 582 may

be a non-abrasive pad without abrasive particles, and the planarizing solution 587 can be a slurry with abrasive particles and chemicals to remove material from the substrate 110.

To planarize the substrate 110 with the apparatus 560, the carrier assembly 590 presses the substrate 110 against the planarizing surface 588 of the planarizing pad 582 in the presence of the planarizing solution 587. The drive assembly 595 then orbits the substrate holder 592 about the axis E-E and optionally rotates the substrate holder 592 about the axis F-F to translate the substrate 110 across the planarizing surface 588. As a result, the abrasive particles and/or the chemicals in the planarizing medium remove material from the surface of the substrate 110 in a chemical and/or chemical-mechanical planarization (CMP) process. Accordingly, the planarizing pad 582 can smooth the substrate 110 by removing rough features projecting from the conductive layer 111 of the substrate 110.

In a further aspect of this embodiment, the apparatus 560 can include an electrolyte supply vessel 530 that delivers an electrolyte to the planarizing surface of the planarizing pad 582 with a conduit 537, as described in greater detail with reference to Figure 10. The apparatus 560 can further include a current supply 521 coupled to the support table 580 and/or the top-panel 581 to supply an electrical current to electrodes positioned in the support table 580 and/or the top-panel 581. Accordingly, the apparatus 560 can electrolytically remove material from the conductive layer 111 in a manner similar to that described above with reference to Figures 1-8C.

In one aspect of an embodiment of the apparatus 560 described above with reference to Figure 9, material can be sequentially removed from the conductive layer 111 of the substrate 110 first by an electrolytic process and then by a CMP process. For example, the electrolytic process can remove material from the conductive layer 111 in a manner that roughens the conductive layer 111. After a selected period of electrolytic processing time has elapsed, the electrolytic processing operation can be halted and additional material can be removed via CMP processing. Alternatively, the electrolytic process and the CMP process can be conducted simultaneously. In either of these processing arrangements, one feature of an embodiment of the apparatus 560 described above with reference to Figure 9 is that the same apparatus 560 can planarize the substrate 110 via CMP and remove material from the substrate 110 via an electrolytic process. An advantage of this arrangement is that the substrate 110 need not be moved from one apparatus to another to undergo both CMP and electrolytic processing.

Another advantage of an embodiment of the apparatus 560 described above with reference to Figure 9 is that the processes, when used in conjunction with each other, is expected to remove material from the substrate 110 more quickly and accurately than some conventional processes. For example, as described above, the electrolytic process can remove relatively large amounts of material in a manner that roughens the microelectronic substrate 110, and the planarizing process can remove material on a finer scale in a manner that smoothes and/or flattens the microelectronic substrate 110.

Figure 10 is a partially exploded, partially schematic isometric view of a portion of the apparatus 560 described above with reference to Figure 9. In one aspect of an embodiment shown in Figure 10, the top-panel 581 houses a plurality of electrode pairs 570, each of which includes a first electrode 520a and a second electrode 520b. The first electrodes 520a are coupled to a first lead 528a and the second electrodes 520b are coupled to a second lead 528b. The first and second leads 528a and 528b are coupled to the current source 521 (Figure 9). In one aspect of this embodiment, the first electrode 520a can be separated from the second electrodes 520b by an electrode dielectric layer 529a that includes Teflon™ or another suitable dielectric material. The electrode dielectric layer 529a can accordingly control the volume and dielectric constant of the region between the first and second electrodes 520a and 520b to control electrical coupling between the electrodes.

The electrodes 520a and 520b can be electrically coupled to the microelectronic substrate 110 (Figure 9) by the planarizing pad 582. In one aspect of this embodiment, the planarizing pad 582 is saturated with an electrolyte 531 supplied by the supply conduits 537 through apertures 538 in the top-panel 581 just beneath the planarizing pad 582. Accordingly, the electrodes 520a and 520b are selected to be compatible with the electrolyte 531. In an alternate arrangement, the electrolyte 531 can be supplied to the planarizing pad 582 from above (for example, by disposing the electrolyte 531 in the planarizing liquid 587) rather than through the top-panel 581. Accordingly, the planarizing pad 582 can include a pad dielectric layer 529b positioned between the planarizing pad 582 and the electrodes 520a and 520b. When the pad dielectric layer 529b is in place, the electrodes 520a and 520b are isolated from physical contact with the electrolyte 531 and can accordingly be selected from materials that are not necessarily compatible with the electrolyte 531.

In either of the embodiments described above with reference to Figure 10, the planarizing pad 582 can provide several advantages over some conventional electrolytic arrangements. For example, the planarizing pad 582 can uniformly separate the electrodes 520a and 520b from the microelectronic substrate 110 (Figure 9), which can increase the uniformity with which the electrolytic process removes material from the conductive layer 111 (Figure 9). The planarizing pad 582 can also have abrasive particles 589 for planarizing the microelectronic substrate 110 in the manner described above with reference to Figure 9. Furthermore, the planarizing pad 582 can filter carbon or other material that erodes from the electrodes 520a and 520b to prevent the electrode material from contacting the microelectronic substrate 110. Still further, the planarizing pad 582 can act as a sponge to retain the electrolyte 531 in close proximity to the microelectronic substrate 110.

Figure 11 is a partially schematic, cross-sectional side elevational view of a rotary apparatus 660 for planarizing and/or electrolytically processing the microelectronic substrate 110 in accordance with another embodiment of the invention. In one aspect of this embodiment, the apparatus 660 has a generally circular platen or table 680, a carrier assembly 690, a planarizing pad 682 positioned on the table 680, and a planarizing liquid 687 on the planarizing pad 682. The planarizing pad 682 can be a fixed abrasive planarizing pad or, alternatively, the planarizing liquid 687 can be a slurry having a suspension of abrasive elements and the planarizing pad 682 can be a non-abrasive pad. A drive assembly 695 rotates (arrow "*G*") and/or reciprocates (arrow "*H*") the platen 680 to move the planarizing pad 682 during planarization.

The carrier assembly 690 controls and protects the microelectronic substrate 110 during planarization. The carrier assembly 690 typically has a substrate holder 692 with a pad 694 that holds the microelectronic substrate 110 via suction. A drive assembly 696 of the carrier assembly 690 typically rotates and/or translates the substrate holder 692 (arrows "*I*" and "*J*," respectively). Alternatively, the substrate holder 692 may include a weighted, free-floating disk (not shown) that slides over the planarizing pad 682.

To planarize the microelectronic substrate 110 with the apparatus 660, the carrier assembly 690 presses the microelectronic substrate 110 against a planarizing surface 688 of the planarizing pad 682. The platen 680 and/or the substrate holder 692 then move relative to one another to translate the microelectronic substrate 110 across the planarizing surface 688. As a result, the abrasive particles in the planarizing pad 682 and/or the

chemicals in the planarizing liquid 687 remove material from the surface of the microelectronic substrate 110.

The apparatus 660 can also include a current source 621 coupled with leads 628a and 628b to one or more electrode pairs 670 (one of which is shown in Figure 11). The electrode pairs 670 can be integrated with the platen 680 in generally the same manner with which the electrodes 520a and 520b (Figure 10) are integrated with the top panel 581 (Figure 10). Alternatively, the electrode pairs 670 can be integrated with the planarizing pad 682. In either embodiment, the electrode pairs 670 can include electrodes having shapes and configurations generally similar to any of those described above with reference to Figures 3-10 to electrolytically remove conductive material from the microelectronic substrate 110. The electrolytic process can be carried out before, during or after the CMP process, as described above with reference to Figure 9.

Figure 12A is a schematic circuit representation of some of the components described above with reference to Figure 10. The circuit analogy can also apply to any of the arrangements described above with reference to Figures 3-11. As shown schematically in Figure 12A, the current source 521 is coupled to the first electrode 520a and the second electrode 520b with leads 528a and 528b respectively. The electrodes 520a and 520b are coupled to the microelectronic substrate 110 with the electrolyte 531 in an arrangement that can be represented schematically by two sets of parallel capacitors and resistors. A third capacitor and resistor schematically indicates that the microelectronic substrate 110 “floats” relative to ground or another potential.

In one aspect of an embodiment shown in Figure 12A, the current source 521 can be coupled to an amplitude modulator 522 that modulates the signal produced by the current source 521, as is shown in Figure 12B. Accordingly, the current source 521 can generate a high-frequency wave 804, and the amplitude modulator 522 can superimpose a low-frequency wave 802 on the high-frequency wave 804. For example, the high-frequency wave 804 can include a series of positive or negative voltage spikes contained within a square wave envelope defined by the low-frequency wave 802. Each spike of the high-frequency wave 804 can have a relatively steep rise time slope to transfer charge through the dielectric to the electrolyte, and a more gradual fall time slope. The fall time slope can define a straight line, as indicated by high-frequency wave 804, or a curved line, as indicated by high-frequency wave 804a. In other embodiments, the high-frequency wave 804 and the

low-frequency wave 802 can have other shapes depending, for example, on the particular characteristics of the dielectric material and electrolyte adjacent to the electrodes 420, the characteristics of the substrate 110, and/or the target rate at which material is to be removed from the substrate 110.

An advantage of this arrangement is that the high frequency signal can transmit the required electrical energy from the electrodes 520a and 520b to the microelectronic substrate 110, while the low frequency superimposed signal can more effectively promote the electrochemical reaction between the electrolyte 531 and the conductive layer 111 of the microelectronic substrate 110. Accordingly, any of the embodiments described above with reference to Figures 3-11 can include an amplitude modulator in addition to a current source.

From the foregoing, it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

CLAIMS

1. A method for removing an electrically conductive material from a microelectronic substrate, comprising:

positioning a first conductive electrode proximate to the microelectronic substrate;

positioning a second conductive electrode proximate to the microelectronic substrate and spaced apart from the first conductive electrode; and

removing the conductive material from the microelectronic substrate by passing a varying current through the first and second electrodes while the first and second electrodes are spaced apart from the conductive material of the microelectronic substrate.

2. The method of claim 1, further comprising:

engaging the microelectronic substrate with a planarizing medium while the microelectronic substrate is positioned proximate to the electrodes; and

moving at least one of the microelectronic substrate and the planarizing medium relative to the other to remove material from the microelectronic substrate by a chemical and/or chemical-mechanical process.

3. The method of claim 1 wherein the microelectronic substrate has a surface facing toward the first and second electrodes, further comprising:

selecting the first and second electrodes to have a combined surface area facing toward the surface of the microelectronic substrate that is less than the area of the surface of the microelectronic substrate; and

moving at least one of the microelectronic substrates and the electrodes relative to the other while applying an electrical current to the at least one electrode.

4. The method of claim 1, further comprising disposing a liquid and/or gel electrolyte between the electrodes and the microelectronic substrate.

5. The method of claim 1, further comprising disposing a dielectric layer between the microelectronic substrate and the first electrode.

6. The method of claim 1, further comprising varying an amplitude and/or polarity of the current at a first frequency and superimposing on the first frequency an amplitude variation having a second frequency less than the first frequency.

7. The method of claim 1 wherein the microelectronic substrate has a planform shape, further comprising selecting the first electrode to have a planform shape generally similar to a first portion of the planform shape of the microelectronic substrate and selecting the second electrode to have a planform shape generally similar to a second portion of the planform shape of the microelectronic substrate.

8. The method of claim 1 wherein the first and second electrodes define an electrode pair and the conductive material is a first portion of conductive material, and wherein the method further comprises:

positioning a second electrode pair proximate to the microelectronic substrate; and

applying a varying current to the second electrode pair to remove a second portion of conductive material from the microelectronic substrate.

9. The method of claim 1 wherein applying a varying current includes applying at least one of a single phase and a multi-phase alternating current to at least one of the first and second electrodes.

10. The method of claim 1 wherein the microelectronic substrate has a surface facing toward the first and second electrodes, further comprising selecting the first and second electrodes to have a combined surface area facing toward the surface of the microelectronic substrate that is approximately equal to the surface of the microelectronic substrate.

11. The method of claim 1, further comprising controlling a rate at which the conductive material is removed from the microelectronic substrate by controlling a distance between at least one of the electrodes and the microelectronic substrate.

12. The method of claim 1, further comprising controlling a rate at which the conductive material is removed from the microelectronic substrate by spacing a first portion of the first electrode a first distance away from a first region of the microelectronic substrate and spacing a second portion of the first electrode a second distance away from a second region of the electrode with the first distance being different than the second distance.

13. The method of claim 1, further comprising engaging the microelectronic substrate with a planarizing medium and moving at least one of the microelectronic substrate and the planarizing medium relative to the other after applying an electrical current to the electrodes and without removing the microelectronic substrate from a region proximate to the electrodes.

14. The method of claim 1 wherein removing the conductive material by applying a varying current includes roughening a surface of the conductive material to form a roughened region, further comprising smoothing the roughened region by engaging the microelectronic substrate with a planarizing medium adjacent to the electrodes and moving at least one of the microelectronic substrate and the planarizing medium relative to the other.

15. The method of claim 1, further comprising:

at least partially immersing the microelectronic substrate in a liquid electrolyte;

moving portions of the electrically conductive material from the microelectronic substrate to the liquid electrolyte; and

removing the portions from the liquid electrolyte.

16. The method of claim 1, further comprising selecting the electrically conductive material to include tungsten, tantalum, gold, copper and/or platinum.

17. The method of claim 1, further comprising selecting an electrolyte adjacent to the microelectronic substrate to include hydrochloric acid.

18. The method of claim 1, further comprising selecting a dielectric material between the microelectronic substrate and the electrodes to include Teflon™.

19. The method of claim 1, further comprising:

disposing a first quantity of an electrolyte between the conductive material and the electrodes only in a first region of the microelectronic substrate immediately proximate to the electrodes;

moving the microelectronic substrate and/or the electrodes to align a second region of the microelectronic substrate with the electrodes; and

disposing a second quantity of the electrolyte between the conductive material and the electrodes only in the second region of the microelectronic substrate.

20. The method of claim 1, further comprising:

disposing a first electrolyte adjacent to the first electrode;

disposing a second electrolyte different than the first electrolyte adjacent to the conductive material of the microelectronic substrate; and

at least restricting movement of the second electrolyte toward the first electrode.

21. The method of claim 1, further comprising:

generating a signal corresponding to a rate at which the conductive material is removed from the microelectronic substrate and/or an amount of conductive material remaining on the microelectronic substrate; and

controlling an interaction between the microelectronic substrate and the electrodes based on the input signal.

22. The method of claim 1, further comprising at least restricting contact between the first electrode and a liquid adjacent to the first conductive material of the

microelectronic substrate by disposing a dielectric film between the first electrode and the liquid.

23. A method for removing an electrically conductive material from a microelectronic substrate, comprising:

positioning a first conductive electrode proximate to the microelectronic substrate;

positioning a second conductive electrode proximate to the microelectronic substrate and spaced apart from the first conductive electrode; and

removing the conductive material from the microelectronic substrate by passing a varying current through the first and second electrodes without contacting the first and second electrodes directly with the conductive material of the microelectronic substrate.

24. The method of claim 23, further comprising varying an amplitude and/or polarity of the current at a first frequency and superimposing on the first frequency an amplitude variation having a second frequency less than the first frequency.

25. The method of claim 23 wherein the first and second electrodes define an electrode pair and the conductive material is a first portion of conductive material, and wherein the method further comprises:

positioning a second electrode pair proximate to the microelectronic substrate; and

applying a varying current to the second electrode pair to remove a second portion of conductive material from the microelectronic substrate.

26. The method of claim 23, further comprising:

engaging the microelectronic substrate with a planarizing medium while the microelectronic substrate is positioned proximate to the electrodes; and

moving at least one of the microelectronic substrate and the planarizing medium relative to the other.

27. The method of claim 23, further comprising:

disposing a first quantity of an electrolyte between the conductive material and the electrodes only in a first region of the microelectronic substrate immediately proximate to the electrodes;

moving the microelectronic substrate and/or the electrodes to align a second region of the microelectronic substrate with the electrodes; and

disposing a second quantity of the electrolyte between the conductive material and the electrodes only in the second region of the microelectronic substrate.

28. The method of claim 23, further comprising:

disposing a first electrolyte adjacent to the first electrode;

disposing a second electrolyte different than the first electrolyte adjacent to the conductive material of the microelectronic substrate; and

at least restricting movement of the second electrolyte toward the first electrode.

29. A method for forming a planarizing medium, comprising:

forming a planarizing pad body having a planarizing surface to engage a surface of a microelectronic substrate;

disposing a first electrode at least adjacent to the planarizing pad body and spaced apart from the planarizing surface with the first electrode coupleable to a source of varying current;

disposing a second electrode at least adjacent to the planarizing pad body with the second electrode spaced apart from the first electrode; and

disposing a dielectric material between the first and second electrodes.

30. The method of claim 29, further comprising selecting the first electrode to include a carbonaceous material.

31. The method of claim 29, further comprising fixedly disposing a plurality of abrasive elements in the planarizing pad body at least proximate to the planarizing surface.

32. The method of claim 29, further comprising disposing a film between the planarizing surface and the electrodes

33. A method for removing an electrically conductive material from a microelectronic substrate, comprising:

positioning a first conductive electrode proximate to the conductive material of the microelectronic substrate;

positioning a second conductive electrode proximate to the conductive material of the microelectronic substrate and spaced apart from the first conductive electrode;

disposing a first electrolyte adjacent to at least one of the first and second electrodes;

disposing a second electrolyte different than the first electrolyte adjacent to the conductive material of the microelectronic substrate;

at least restricting motion of the second electrolyte toward the one electrode; and

removing the conductive material from the microelectronic substrate by passing a varying current through the first and second electrodes while the first and second electrodes are spaced apart from the conductive material of the microelectronic substrate.

34. The method of claim 33 wherein at least restricting motion of the second electrolyte includes disposing a permeable membrane between the one electrode and the microelectronic substrate and passing the first electrolyte through the membrane.

35. The method of claim 33, further comprising selecting the first electrolyte to include sodium chloride, potassium chloride, and/or or copper sulfate.

36. The method of claim 33, further comprising selecting the second electrolyte to include hydrochloric acid.

37. A method for removing an electrically conductive material from a microelectronic substrate, comprising:

positioning a first conductive electrode proximate to a first portion of the microelectronic substrate;

positioning a second conductive electrode proximate to the first portion of microelectronic substrate and spaced apart from the first conductive electrode, the first and second electrodes defining an electrode pair;

removing the conductive material from the first portion of the microelectronic substrate by passing a varying current through the first and second electrodes while the first and second electrodes are spaced apart from the conductive material of the microelectronic substrate;

moving at least one of the microelectronic substrate and the electrode pair relative to the other to align a second portion of the microelectronic substrate with the electrode pair; and

removing the conductive material from the second portion of the microelectronic substrate by applying a varying current to at least one of the first and second electrodes while the first and second electrodes are spaced apart from the conductive material of the microelectronic substrate.

38. The method of claim 37, further comprising:

directing a first flow of electrolyte only to the first portion of the microelectronic substrate when the electrode pair is proximate to the first potion; and

directing a second flow of electrolyte only to the second portion of the microelectronic substrate when the electrode pair is proximate to the second potion.

39. A method for removing an electrically conductive material from a microelectronic substrate, comprising:

engaging a surface of the microelectronic substrate with a planarizing medium; and

removing at least a portion of the electrically conductive material from the microelectronic substrate by passing a varying electrical current through the microelectronic

substrate while engaging the surface of the microelectronic substrate with the planarizing medium.

40. The method of claim 39, further comprising moving at least one of the microelectronic substrate and the planarizing medium relative to the other.

41. The method of claim 39, further comprising:

spacing a first electrode and a second electrode apart from the microelectronic substrate and apart from each other; and

coupling at least one of the electrodes to a source of varying current to pass the current from the one electrode, through an electrolyte adjacent to the microelectronic substrate and to the other electrode.

42. The method of claim 39 wherein removing the conductive material by applying a varying current includes roughening a surface of the conductive material to form a roughened region, further comprising smoothing the roughened region by moving at least one of the microelectronic substrate and the planarizing medium relative to the other.

43. A method for removing an electrically conductive material from a microelectronic substrate, comprising:

positioning a first conductive electrode at least proximate to a first portion of the microelectronic substrate;

positioning a second conductive electrode at least proximate to the first portion of the microelectronic substrate and spaced apart from the first conductive electrode, the first and second electrodes defining a first electrode pair;

positioning a second electrode pair at least proximate to a second portion of the microelectronic substrate, the second electrode pair including a third electrode and a fourth electrode spaced apart from the third electrode; and

removing the conductive material from the microelectronic substrate by passing a first varying current through the first and second electrodes and passing a second varying current through the third and fourth electrodes.

44. The method of claim 43, further comprising spacing the first and second electrodes apart from the microelectronic substrate while applying the first varying current.

45. The method of claim 43, further comprising spacing the first electrode pair a first distance from a surface of the microelectronic substrate and spacing the second electrode pair a second distance from the surface of the microelectronic substrate with the first distance greater than the second distance.

46. The method of claim 43, further comprising:

spacing the first and second electrode pair apart from each other by a first distance;

spacing a third and fourth electrode pair apart from each other by a second distance greater than the first distance, with each of the third and fourth electrode pairs including two spaced apart electrodes;

aligning the third electrode pair with a third portion of the microelectronic substrate and aligning the fourth electrode pair with a fourth portion of the microelectronic substrate; and

removing the conductive material from the third and fourth portions of the microelectronic substrate by passing a third varying current through the third electrode pair and passing a fourth varying current through the fourth electrode pair.

47. The method of claim 43 wherein the first varying current is approximately identical to the second varying current.

48. The method of claim 43 wherein an amplitude of the first varying current is greater than an amplitude of the second varying current.

49. An apparatus for removing conductive material from a microelectronic substrate, comprising:

a support member having at least one engaging surface to support the microelectronic substrate;

a first electrode spaced apart from the support member and from the microelectronic substrate when the microelectronic substrate is supported by the support member; and

a second electrode spaced apart from the support member and from the microelectronic substrate when the microelectronic substrate is supported by the support member, the second electrode being spaced apart from the first electrode, at least one of the first and second electrodes being coupleable to a source of varying current.

50. The apparatus of claim 49 wherein the first and second electrodes define an electrode pair and at least one of the electrode pair and the support member is movable relative to the other while the at least one of the first and second electrodes is coupled to the source of varying current.

51. The apparatus of claim 49, further comprising an electrolyte vessel configured to support a liquid electrolyte, and further wherein the support member is positioned relative to the electrolyte vessel to support the microelectronic substrate within the vessel.

52. The apparatus of claim 49, further comprising a dielectric layer at least proximate to the first electrode, the dielectric layer being positioned between the microelectronic substrate and the first electrode when the microelectronic substrate is supported by the support member.

53. The apparatus of claim 49, further comprising the current source, the current source configured to vary an amplitude of the current at a first frequency, the current source including an amplitude modulator to superimpose on the first frequency an amplitude and/or polarity variation having a second frequency less than the first frequency.

54. The apparatus of claim 49 wherein the microelectronic substrate has a planform shape, the first electrode has a planform shape generally similar to a first portion of the planform shape of the microelectronic substrate and the second electrode has a planform

shape generally similar to a second portion of the planform shape of the microelectronic substrate.

55. The apparatus of claim 49 wherein the first and second electrodes define a first electrode pair, and wherein the apparatus further comprises:

a third electrode spaced apart from the support member and from the microelectronic substrate when the microelectronic substrate is supported by the support member; and

a fourth electrode spaced apart from the support member and from the microelectronic substrate when the microelectronic substrate is supported by the support member, the fourth electrode being spaced apart from the third electrode, at least one of the third and fourth electrodes being coupleable to a source of varying current.

56. The apparatus of claim 49, further comprising the current source, and further wherein the current source includes a single phase or a multi-phase alternating current supply.

57. The apparatus of claim 49 wherein the microelectronic substrate has a surface facing toward the first and second electrodes, and further wherein the first and second electrodes have a combined surface area facing toward the surface of the microelectronic substrate that is approximately equal to the surface area of the microelectronic substrate.

58. The apparatus of claim 49 wherein the microelectronic substrate has a surface facing toward the first and second electrodes, and further wherein the first and second electrodes have a combined surface area facing toward the surface of the microelectronic substrate that is less than the area of the surface of the microelectronic substrate, at least one of the microelectronic substrate and the electrodes being moveable relative to the other while an electrical current is applied to the at least one electrode.

59. The apparatus of claim 49 wherein the first and second electrodes define an electrode pair, further wherein at least one of the electrode pair and the support member is

moveable toward and away from the other to control a distance between the electrode pair and the microelectronic substrate when the microelectronic substrate is supported by the support member.

60. The apparatus of claim 49 wherein at least one of the first electrode and the support member is movable relative to the other and the first electrode includes a first surface portion and a second surface portion, the first and second surface portions facing the microelectronic substrate when the microelectronic substrate is supported by the support member, the first portion being positioned further from the microelectronic substrate than the second portion when a first region of the microelectronic substrate opposite the first portion has a slower velocity relative to the first electrode than does a second region of the microelectronic substrate opposite the second portion of the first electrode.

61. The apparatus of claim 49, further comprising a planarizing medium positioned proximate to the support member to engage the support member when the support member engages the microelectronic substrate.

62. The apparatus of claim 49, further comprising a liquid or gel electrolyte adjacent to the first electrode.

63. The apparatus of claim 49, further comprising a conduit coupleable to a source of electrolyte, the conduit having an outlet aperture proximate to the first and second electrodes.

64. The apparatus of claim 49, further comprising a sensor positioned at least proximate to the support member to detect a rate at which the conductive material is removed from the microelectronic substrate and/or an amount of conductive material remaining on the microelectronic substrate.

65. The apparatus of claim 49, further comprising:

the current source coupled to the at least one electrode; and

a sensor positioned at least proximate to the support member to detect a rate at which the conductive material is removed from the microelectronic substrate and/or an amount of conductive material remaining on the microelectronic substrate, the sensor being coupled to the current source and/or at least one of the electrodes to control an electrical potential imparted to the microelectronic substrate when the microelectronic substrate is supported by the support member.

66. An apparatus for removing a conductive material from a microelectronic substrate, comprising:

a carrier having at least one engaging surface to support a microelectronic substrate;

a polishing pad proximate to the carrier and having a polishing surface to engage the microelectronic substrate, at least one of the polishing pad and the carrier being movable relative to the other;

a first electrode proximate to the polishing surface; and

a second electrode proximate to the polishing surface and spaced apart from the first electrode, at least one of the first and second electrodes being coupleable to a source of varying electrical current.

67. The apparatus of claim 66 wherein the first and second electrodes define an electrode pair and at least one of the electrode pair and the carrier is movable relative to the other while the at least one of the first and second electrodes is coupled to the source of varying current.

68. The apparatus of claim 66, further comprising the current source, further wherein the current source is configured to vary an amplitude of the current at a first frequency, still further wherein the current source includes an amplitude modulator to superimpose on the first frequency an amplitude and/or polarity variation having a second frequency less than the first frequency.

69. The apparatus of claim 66 wherein the first and second electrodes define a first electrode pair, and wherein the apparatus further comprises:

a third electrode spaced apart from the carrier and from the microelectronic substrate when the microelectronic substrate is supported by the carrier; and

a fourth electrode spaced apart from the carrier and from the microelectronic substrate when the microelectronic substrate is supported by the carrier, the fourth electrode being spaced apart from the third electrode, at least one of the third and fourth electrodes being coupleable to a source of varying current.

70. The method of claim 66, further comprising:

the current source coupled to the at least one electrode; and

a sensor positioned at least proximate to the support member to detect a rate at which the conductive material is removed from the microelectronic substrate and/or an amount of conductive material remaining on the microelectronic substrate, the sensor being coupled to the current source and/or at least one of the electrodes to control an electrical potential imparted to the microelectronic substrate when the microelectronic substrate is supported by the carrier.

71. An apparatus for removing an electrically conductive material from a microelectronic substrate, comprising:

a support member having an engaging surface to support the microelectronic substrate;

a first conductive electrode spaced apart from the support member and spaced apart from the microelectronic substrate when the microelectronic substrate is supported by the support member;

a second conductive electrode spaced apart from the support member and the first conductive electrode, at least one of the first and second electrodes being coupleable to a source of varying current; and

an electrolyte flow restrictor positioned between the support member and at least one of the conductive electrodes to at least restrict a flow of an electrolyte toward at least one of the first and second electrodes.

72. The apparatus of claim 71, further comprising:

a first electrolyte adjacent to the microelectronic substrate and selected from sodium chloride, potassium chloride and copper sulfate; and

a second electrolyte adjacent to at least one of the electrodes and selected to include hydrochloric acid.

73. The apparatus of claim 71 wherein the flow restrictor includes a permeable membrane.

74. An apparatus for removing an electrically conductive material from a microelectronic substrate, comprising:

a support member having at least one engaging surface to support the microelectronic substrate;

first and second conductive electrodes spaced apart from each other, spaced apart from the support member, and spaced apart from the microelectronic substrate when the microelectronic substrate is supported by the support member, at least one of the first and second electrodes being coupleable to a source of varying current, the first and second electrodes defining an electrode pair, at least one of the support member and the electrode pair being movable relative to the other while the varying current is applied to the at least one of the first an second electrodes.

75. The apparatus of claim 74, further comprising a conduit coupleable to a source of electrolyte and having an aperture positioned proximate to at least one of the electrodes.

76. An apparatus for removing an electrically conductive material from a microelectronic substrate, comprising:

a support member having at least one engaging surface to support the microelectronic substrate;

first and second conductive electrodes spaced apart from each other and defining a first electrode pair, the first electrode pair being at least proximate to the

microelectronic substrate when the microelectronic substrate is supported by the support member, at least one of the first and second electrodes being coupleable to a source of varying current; and

third and fourth conductive electrodes spaced apart from each other and defining a second electrode pair spaced apart from the first electrode pair, the second electrode pair being at least proximate to the microelectronic substrate when the microelectronic substrate is supported by the support member, at least one of the third and fourth electrodes being coupleable to a source of varying current.

77. The apparatus of claim 76 wherein the first and second electrodes are positioned to be spaced apart from the microelectronic substrate when the microelectronic substrate is supported by the support member.

78. The apparatus of claim 76 wherein the first electrode pair is positioned a first distance from a surface of the microelectronic substrate and the second electrode pair is positioned a second distance from the surface of the microelectronic substrate when the support member supports the microelectronic substrate, with the first distance greater than the second distance.

79. The apparatus of claim 76, further comprising a third and fourth electrode pair, the third and fourth electrode pairs each including two spaced apart electrodes, the first and second electrode pair spaced apart from each other by a first distance and the third and fourth electrode pair spaced apart from each other by a second distance greater than the first distance

80. The apparatus of claim 76 wherein an amplitude of varying current supplied to the first and second electrodes is different than an amplitude of varying current supplied to the third and fourth electrodes.

81. The apparatus of claim 76 wherein a frequency of varying current supplied to the first and second electrodes is higher than a frequency of varying current supplied to the third and fourth electrodes.

METHOD AND APPARATUS FOR REMOVING CONDUCTIVE MATERIAL FROM A MICROELECTRONIC SUBSTRATE

ABSTRACT

A method and apparatus for removing conductive material from a microelectronic substrate. In one embodiment, a support member supports a microelectronic substrate relative to first and second electrodes, which are spaced apart from each other and spaced apart from the microelectronic substrate. One or more electrolytes are disposed between the electrodes and the microelectronic substrate to electrically link the electrodes to the microelectronic substrate. The electrodes are then coupled to a source of varying current that electrically removes the conductive material from the substrate. The microelectronic substrate and/or the electrodes can be moved relative to each other to position the electrodes relative to a selected portion of the microelectronic substrate, and the electrodes can be integrated with a planarizing portion of the apparatus to remove material from the conductive layer by chemical-mechanical planarization.

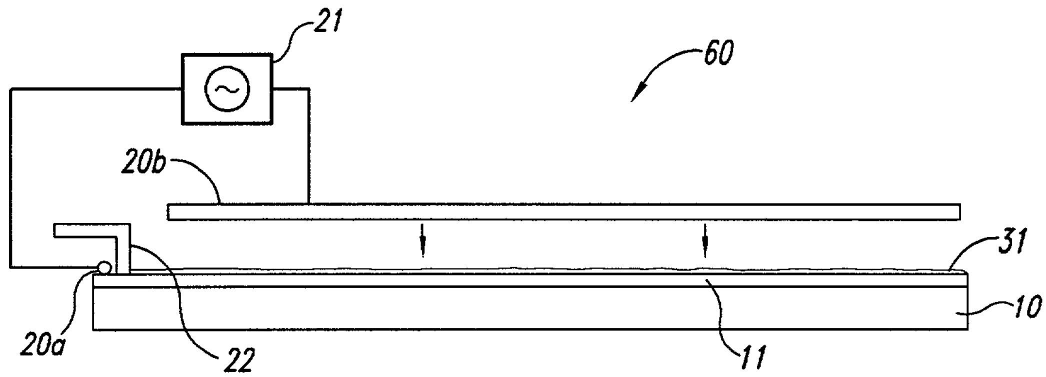


Fig. 1
(Prior Art)

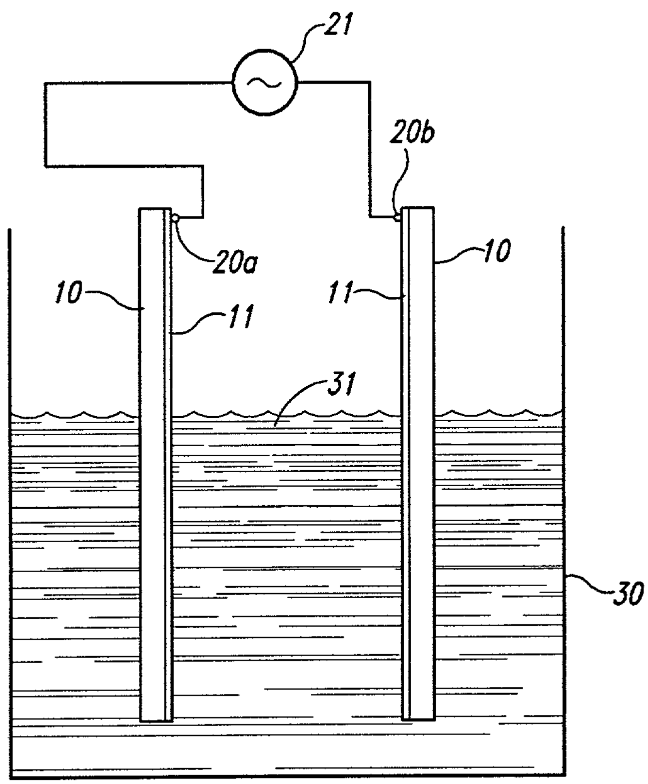
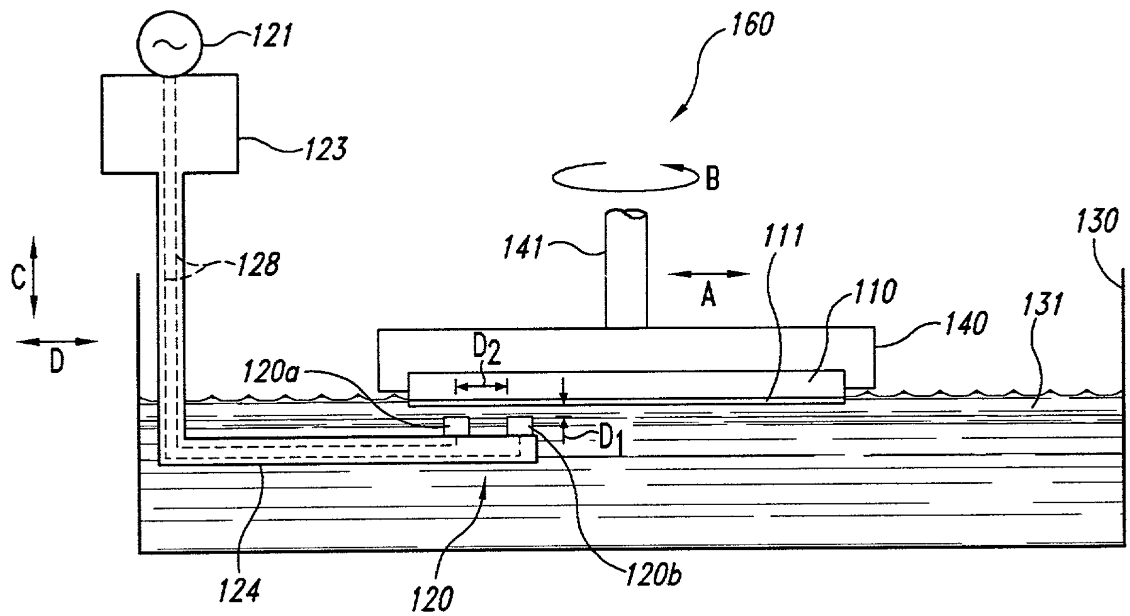


Fig. 2
(Prior Art)



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D2
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D1
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120
120b

Fig. 3

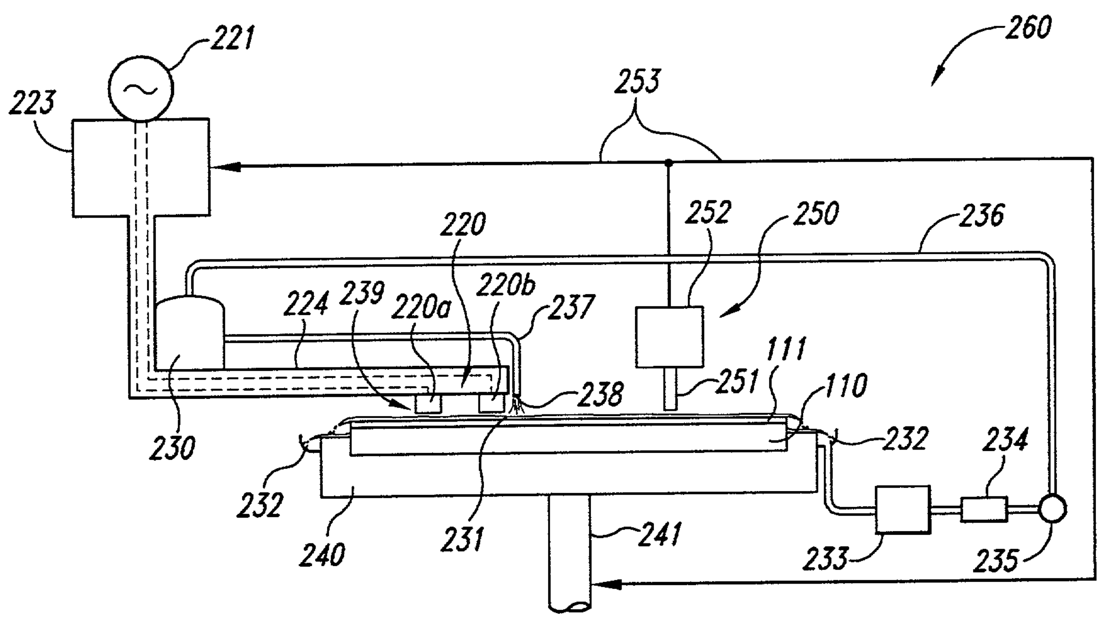

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Fig. 4

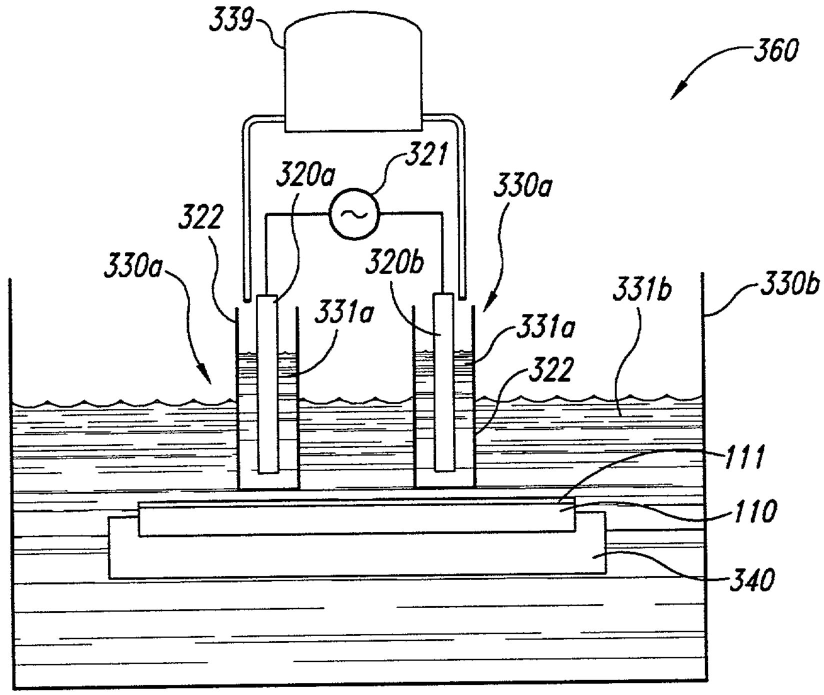
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Fig. 5

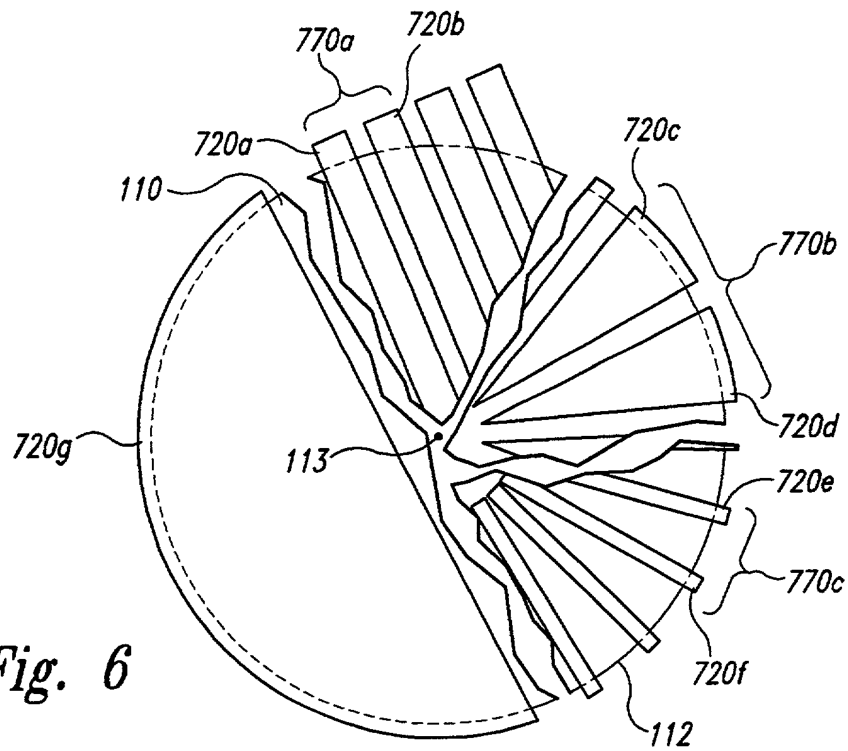
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Fig. 6

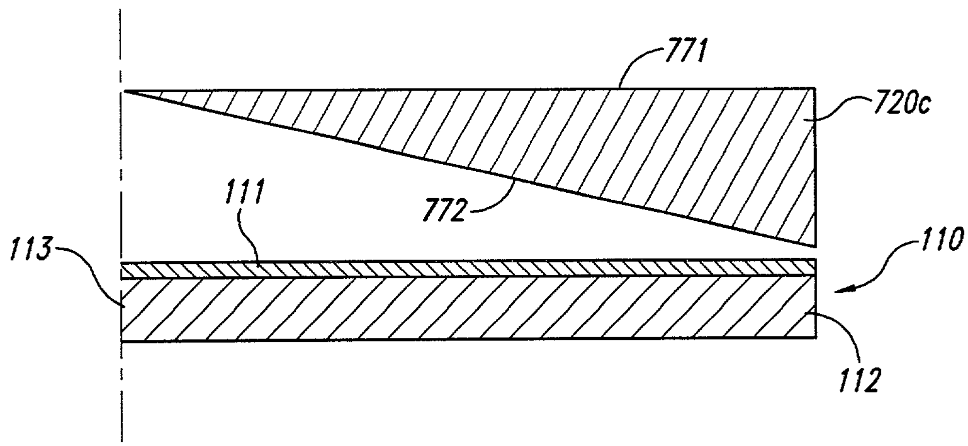
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Fig. 7

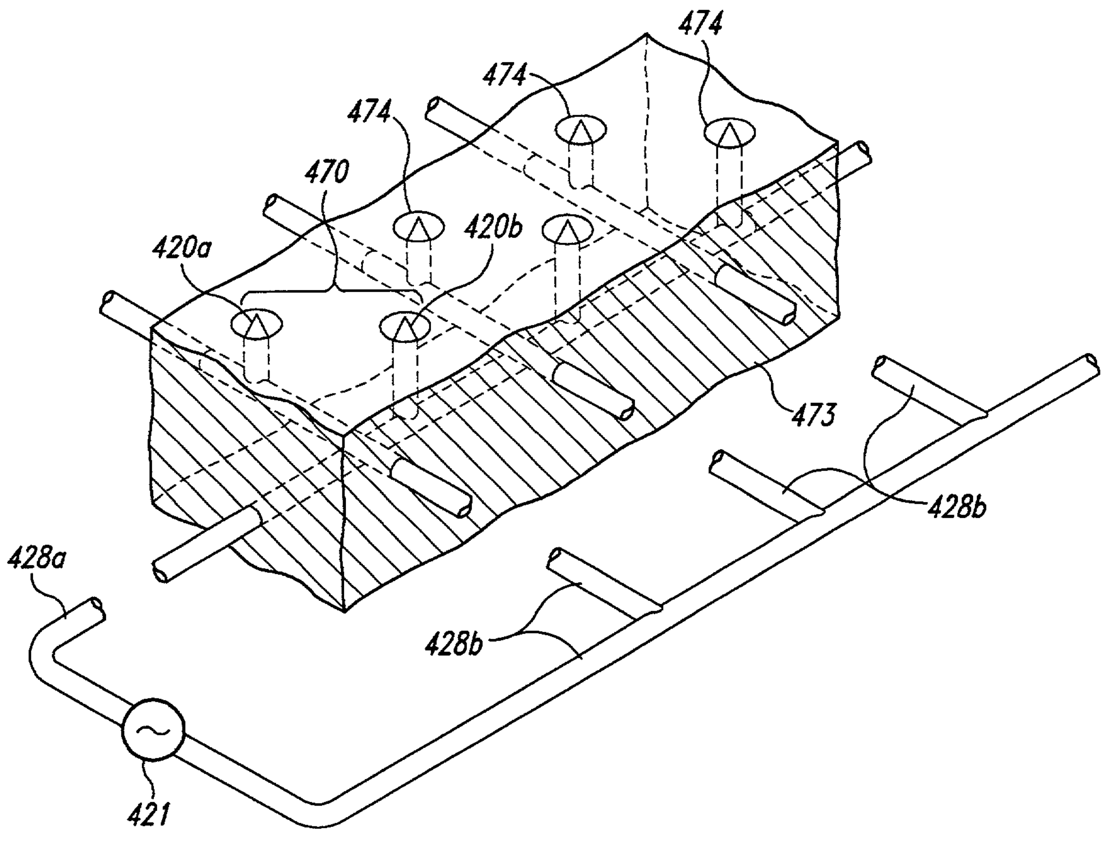
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Fig. 8A

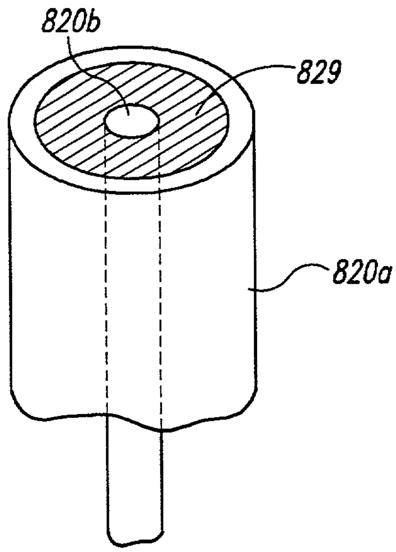


Fig. 8B

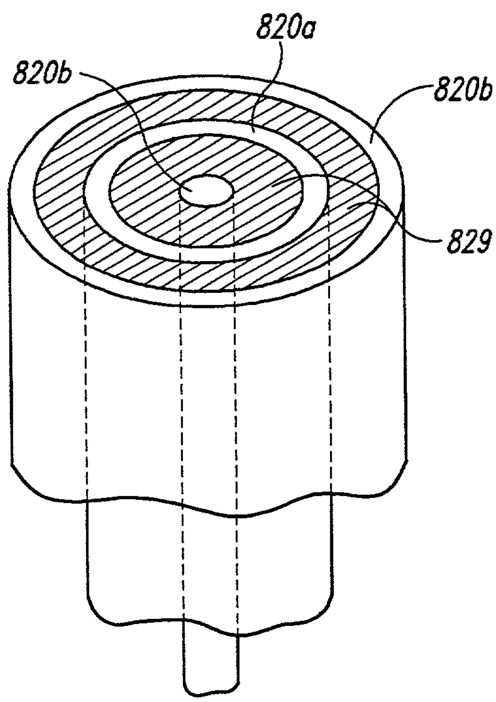
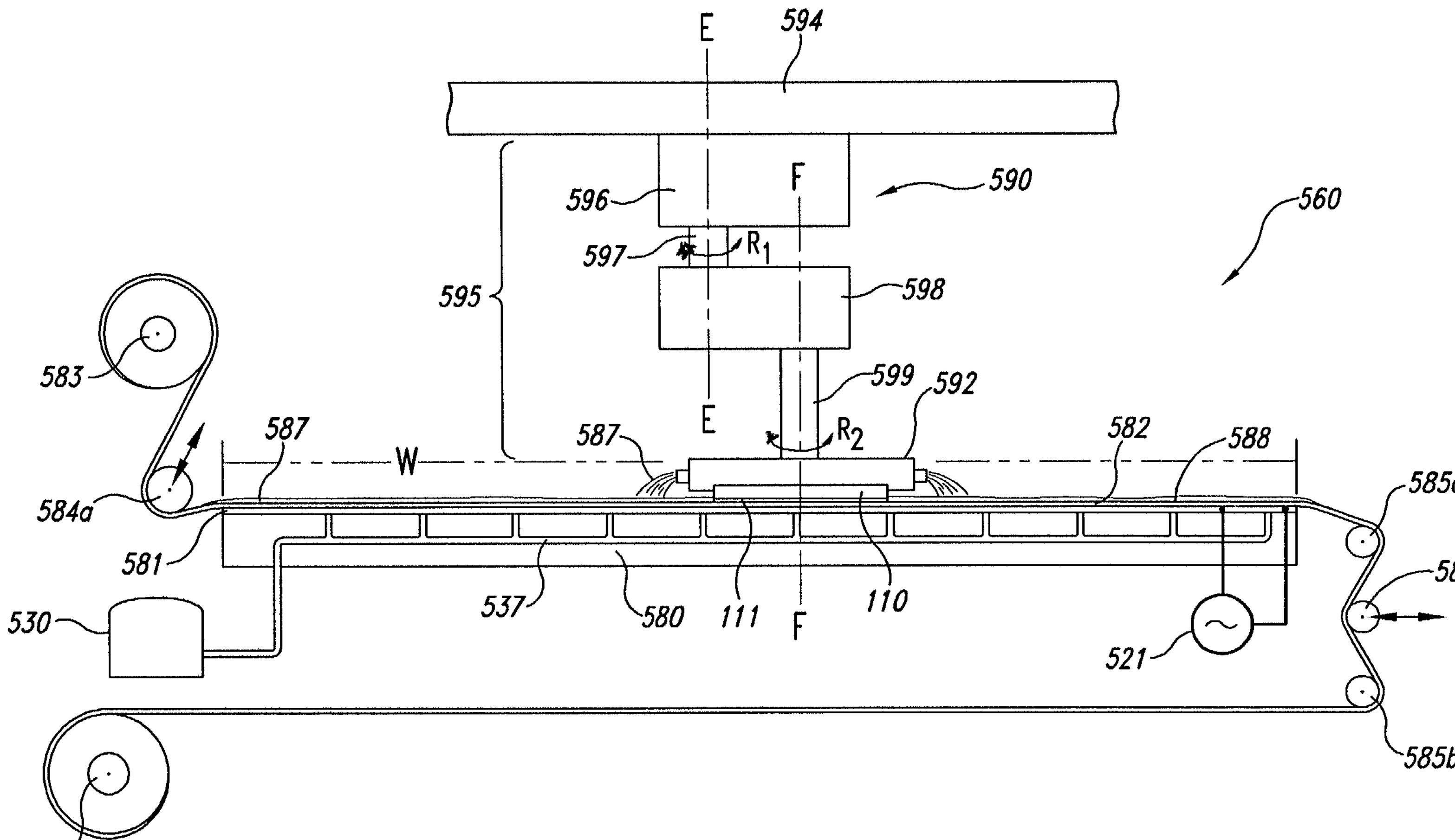


Fig. 8C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592
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W
587
E
R2
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537
580
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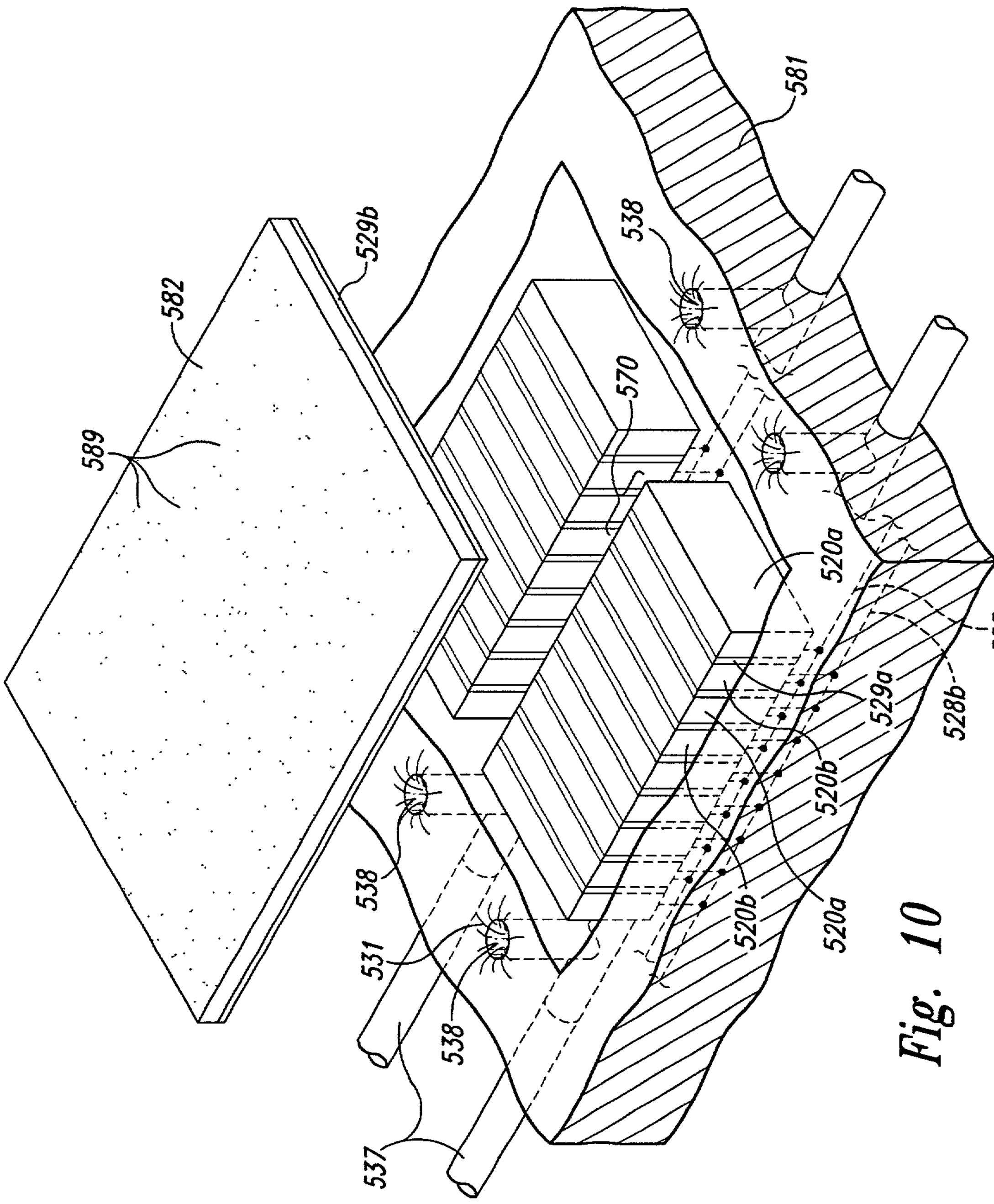
F
110
584b
521
585b
586

Fig. 9



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537

Fig. 10

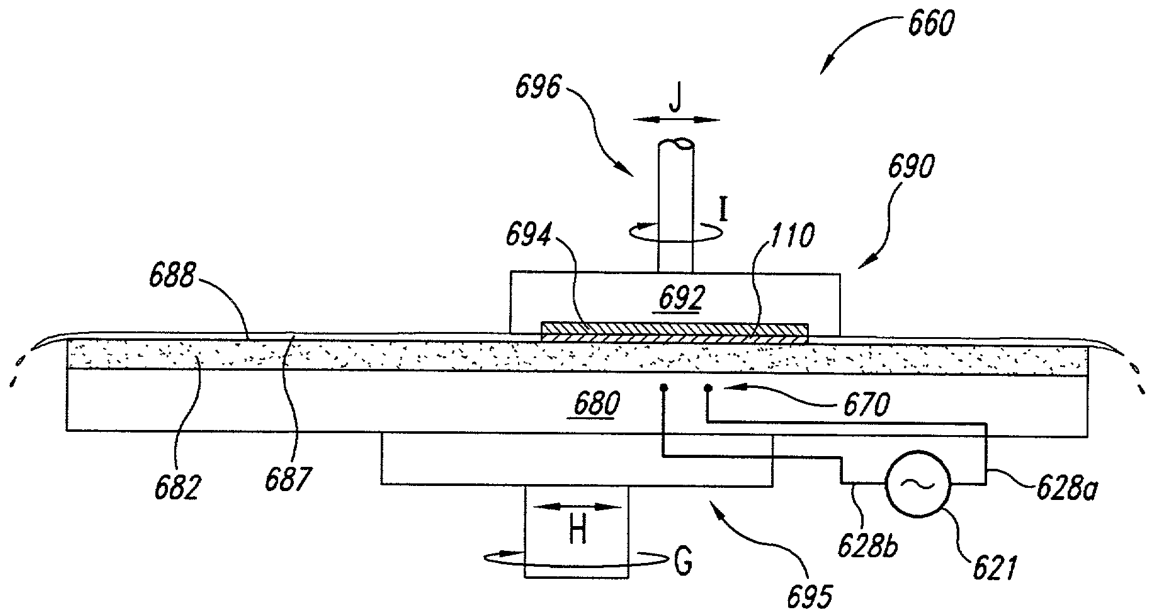

Fig. 11

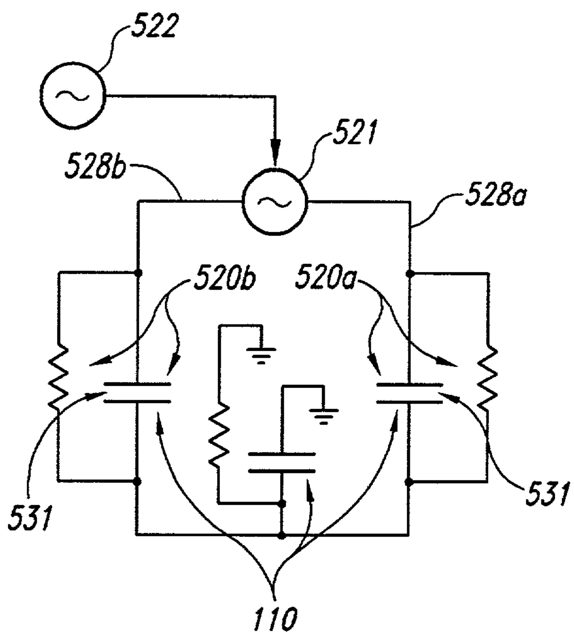

Fig. 12A

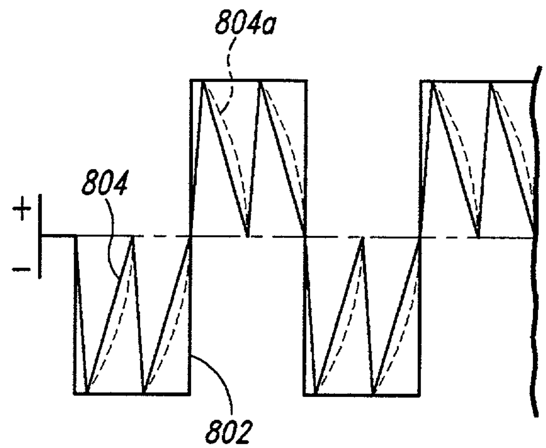

Fig. 12B

DECLARATION

As the below-named inventor, I declare that:

My residence, post office address, and citizenship are as stated below under my name.

I believe I am the original, first, and sole inventor of the subject matter claimed and for which a patent is sought on the invention entitled "METHODS AND APPARATUS FOR REMOVING CONDUCTIVE MATERIAL FROM A MICROELECTRONIC SUBSTRATE" in the foregoing specification and claims.

I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge my duty to disclose information which is material to the patentability of this application in accordance with 37 C.F.R. § 1.56(a).

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further, that these statements were made with the knowledge that the making of willfully false statements and the like is punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and may jeopardize the validity of any patent issuing from this patent application.

Scott E. Moore
Scott E. Moore

Date 8-28-00

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Citizenship	:	United States of America
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PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Scott E. Moore
Filed	:	Concurrently herewith
For	:	METHODS AND APPARATUS FOR REMOVING CONDUCTIVE MATERIAL FROM A MICROELECTRONIC SUBSTRATE

Docket No. : 108298515US

Box Patent Application
Assistant Commissioner for Patents
Washington, DC 20231

ELECTION UNDER 37 C.F.R. §§ 3.71 AND 3.73 AND POWER OF ATTORNEY

Sir:

The undersigned, being Assignee of the entire interest in the above-identified application by virtue of an Assignment filed concurrently herewith, hereby elects, under 37 C.F.R. § 3.71, to prosecute the application to the exclusion of the inventor.

Assignee hereby appoints JERRY A. RIEDINGER, Registration No. 30,582; MAURICE J. PIRIO, Registration No. 33,273; JOHN C. STEWART, Registration No. 40,188; MICHAEL D. BROADDUS, Registration No. 41,637; BRIAN P. MCQUILLEN, Registration No. 41,989; TARANEH MAGHAME, Registration No. 43,768; CATHERINE HONG TRAN, Registration No. 43,960; ROBERT G. WOOLSTON, Registration No. 37,263; PAUL T. PARKER, Registration No. 38,264; JOHN M. WECHKIN, Registration No. 42,216; CHRISTOPHER DALEY-WATSON, Registration No. 34,807; STEVEN D. LAWRENZ, Registration No. 37,376; JAMES A.D. WHITE, Registration No.

43,985; FRANK ABRAMONTE, Registration No. 38,066, along with MICHAEL L. LYNCH, Reg. No. 30,871; WALTER D. FIELDS, Reg. No. 37,130; CHARLES B. BRANTLEY, II, Reg. No. 38,086; KEVIN D. MARTIN, Reg. No. 37,882; and DAVID J. PAUL, Reg. No. 34,692, of Micron Technology, Inc., 8000 South Federal Way, Boise, Idaho 83706-9632 as the principal attorneys with full power of substitution, association, and revocation to prosecute said application, to transact all business in the Patent and Trademark Office connected therewith, and to receive the letters patent therefor. Please direct all direct all telephone calls to John M. Wechkin at (206) 583-8888 and telecopies to (206) 583-8500.

Please direct all communications to:

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P. O. Box 1247
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Attn: John M. Wechkin

Pursuant to 37 C.F.R. § 3.73, the undersigned duly authorized designee of Assignee certifies that the evidentiary documents have been reviewed, specifically the Assignment to MICRON TECHNOLOGY, INC., filed concurrently herewith for recording, a copy of which is attached hereto, and certifies that to the best of my knowledge and belief, title remains in the name of the Assignee.

MICRON TECHNOLOGY, INC.

8-28-01
DATE

Michael L. Lynch
Chief Patent Counsel

Enclosure:
Copy of Assignment